Radiation Sources in the Extreme Ultraviolet and Soft X-ray region

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1. Abstract

Possible extreme ultraviolet (EUV) and soft x-ray (SXR) sources have been identified using the relativistic Flexible atomic code (FAC). Theoretical emission spectra resulting from the 4d-4f and 4p-4d transitions in Pd-like to Rb-like ions of lanthanum through actinium are presented. Characterization of these sources is achieved by applying the unresolved transition array (UTA) model. The resulting mean wavelengths and spectral widths are also shown.

2. Atomic Spectra Calculations

Configuration interaction (CI) calculations were performed with the flexible atomic code (FAC)[1] using the following basis set: $4p^6 4d^N$, $4p^6 4d^{N-1} nl$ and $4p^5 4d^{N+1}$ where $n \leq 8$, $l \leq 3$ and $1 \leq N \leq 10$, resulting in 330 theoretical EUV / SXR emission spectra which were previously presented[2,3]. Due to the huge interest in these elements as next generation lithography sources[4], Gadolinium and terbium are presented in Figure 1 along with maximum peak emission for all elements presented in Figure 2.

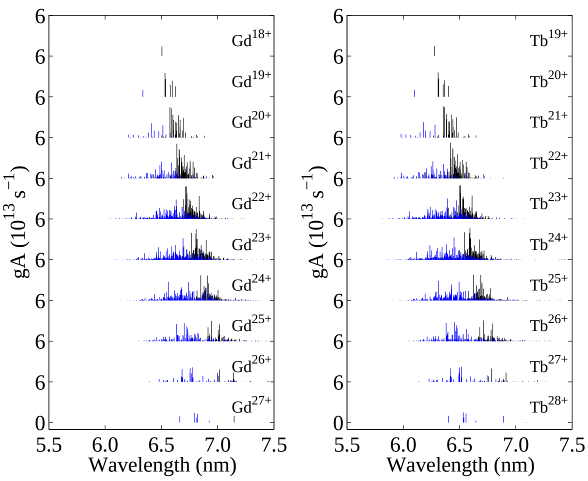

Figure 1: *Gadolinium and Terbium 4d-4f (black) and 4p-4d (blue) spectra computed with the FAC code.*

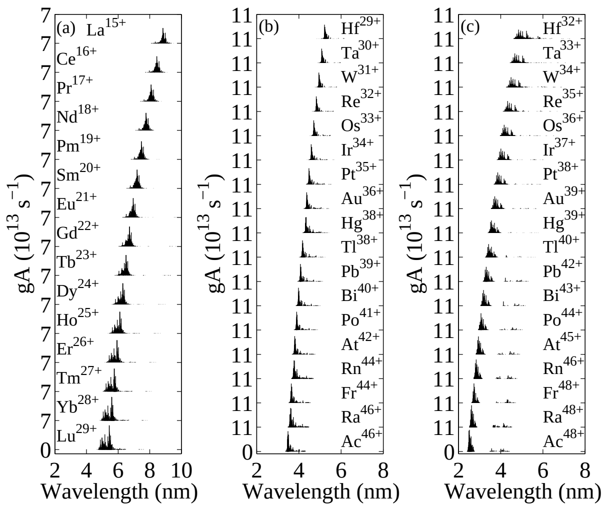

Figure 2: *Maximum peak emission: (a) 4d–4f and 4p–4d UTAs, Z=57–71, (b) 4d-4f UTAs, Z=72–89 and (c) 4p–4d UTAs, Z=72–89.*

3. UTA Statistics

Using the unresolved transition array approach developed by Bauche-Arnoult, Bauche and Klapisch[5–8], where the average and variance of the transition energies ($\bar{E}$ and σ^2) can be expressed as the gA-weighted sums:

$$\bar{E} = \frac{\sum_{j,i<j} g_j A_{ji} E_{ij}}{\sum_{j,i<j} g_j A_{ji}} \quad \text{and} \quad \sigma^2 = \frac{\sum_{j,i<j} g_j A_{ji} \left(\bar{E} - E_{ij}\right)^2}{\sum_{j,i<j} g_j A_{ji}}$$

where A_{ji} is the Einstein coefficient for spontaneous emission from level j to level i, and g_j is the statistical weight of the upper level. The mean wavelength λ_{gA} and the spectral width $\Delta\lambda_{gA}$ of the transition array are defined as $\lambda_{gA} = 10^8/\bar{E}$ and $= \sqrt{8 \ln 2} \times 10^8 \sigma / \bar{E}^2$, where $\bar{E}$ and σ are expressed in cm^{-1} and λ_{gA} and $\Delta\lambda_{gA}$ are in Å. The mean wavelength λ_{gA} and the spectral width $\Delta\lambda_{gA}$ of the 4d-4f and 4p-4d UTAs for Z=57–89 are presented in Figure3.

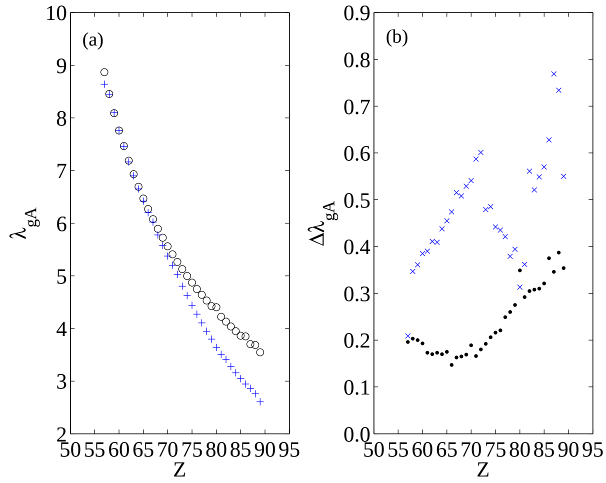

Figure 3: *Mean wavelength (a) and spectral width (b) for the UTAs of lanthanum through actinium;4d-4f (black) and 4p-4d (blue).*

4. Summary

Possible extreme ultraviolet (EUV) and soft x-ray (SXR) sources were identified with FAC and characterized with the UTA model. In future the laser produced plasma (LPP) technique may be used to generate these radiation sources for applications in exciting fields such as microscopy, spectroscopy and lithography.

5. References

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